Stream Sediment Monitoring on the Klamath National Forest 2010

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ABSTRACT

Streambed sediment was measured in low gradient stream channels located near the mouth of 39 watersheds. The effect of forest management is evaluated by comparing the amount of fine sediment in managed and reference streams. Reference watersheds have little or no management and represent the natural variation of background conditions. When compared to reference streams, 10 managed streams had increased fine sediment. To determine if human-related sediment sources could have caused the high values, the dominant sediment source in each watershed is estimated using the Forest Service GEO and USLE models. The models show that roads supply >50% of the total sediment supply in 7 of the 10 managed watersheds, while natural sources can explain the high values in 3 watersheds. The natural background values for streambed sediment are significantly correlated with the percent of the watershed with sandy geology, but only for subsurface sediment and not pool or surface sediment. We found significant but weak correlations between instream sediment and the sediment supply predicted by the GEO and USLE models. In-stream sediment is also correlated with percent equivalent roaded area.

INTRODUCTION

This report is an assessment of in-stream sediment data collected on the Klamath National Forest between 2009 and 2010. The monitoring program is designed to meet the Forest Service monitoring requirements in the Klamath, Scott, Shasta, and Salmon River TMDLs, and two memorandums of understanding between the Forest Service and the Regional Water Quality Control Board (NCWQCB 2009a, b). The program also meets the in-channel monitoring requirement for projects covered under Category B of the Regional Water Board’s Categorical Waiver for management activities on federal land (NCRWQB 2010).

The purpose of in-stream sediment monitoring is to assess the cumulative effect of all past activities in a watershed. Water quality protection for Forest Service activities is achieved through multiple policies and guidelines including the application of best management practices (BMPs), Forest Plan standards, and watershed restoration. The sediment monitoring program evaluates the combined effectiveness of these multiple policies at the watershed scale. On-site monitoring of individual BMPs is evaluated using a different protocol and is reported in a separate report (USFS 2010).

The objectives of the monitoring program are to answer the following questions:

1. What is the reference condition for stream sediment on the Klamath National Forest?

2. Are Forest Service water quality protection measures cumulatively effective at preventing a management-related increase in stream sediment at the watershed scale?

3. Identify management thresholds for the Forest Service cumulative watershed effects models that predict attainment of reference conditions for stream sediment.

METHODS

In-stream sediment is measured using the parameters and methods listed in Table 1. The sample design is outlined in a Quality Assurance Project Plan that was approved by the North Coast Regional Water Board in 2010 (USFS 2010a). A detailed description of the sediment sampling protocols and field forms are available in the Klamath National Forest stream monitoring field guide (Elder 2009).

Compliance Criteria

Forest Service standards for sediment include the Aquatic Conservation Strategy objective to maintain the natural sediment regime. The Klamath National Forest Land and Resource Management Plan has a standard of 15% for streambed-surface sediment <2mm (Table 1, USFS 1994). The North Coast Water Board has developed desired condition values for sediment indices that are expected to support beneficial uses and meet the Basin Plan objectives for fisheries habitat (Table 1, NCRWQCB 2006 and 2007). However, the state's desired condition values were derived from watersheds underlain by the Franciscan Formation and may not reflect the size and volume of sediment produced from the parent material on the Klamath National Forest. Many of the values were developed from literature documenting the habitat needs of salmonids and do not necessarily represent the potential condition of streams on the Klamath National Forest.

To help identify more appropriate sediment targets, the Klamath National Forest measures sediment in reference streams to develop local values for the indices in Table 1. The effect of management is evaluated by comparing sediment in each individual managed stream to the 75th percentile of reference values (Stoddard et al, 2005). The hypothesis tested is:

$$H_0: S_m \leq S_r + e$$

Where: S_m = Value of sediment indicator in a managed stream
S_r = 75th percentile of sediment values in reference streams
e = Survey error

Table 1. Parameters used to measure attainment of water quality standards for sediment. Desired condition values are from NCRWB (2006 and 2007).

Parameter	Desired Condition	Source	Survey Method
Fraction of Pool Volume filled with Sediment (V*)	≤ 0.21 (21%)	Scott River TMDL (NCRWB 2007)	Hilton and Lisle 1993
Subsurface Sediment Percent < 0.85mm Percent < 6.4mm	 ≤ 14% ≤ 30%	 Scott River TMDL (NCRWB 2007)	 Schuet-Hames 1999, Valentine 1995
Surface Sediment Percent < 2.0mm	≤ 15%	USFS (1994)	USFS 2003, Cover 2008

Selection of Watersheds and Sample Sites

A network of monitoring watersheds was developed that covers all of the major tributary streams on the Forest (Figure 1). One sample site was selected in each watershed at a "response reach". Response reaches usually have the lowest stream gradient in the watershed and are the locations most likely to accumulate fine sediment in response to increased sediment supply. Response reaches are typically located near the mouth of the stream and reflect the cumulative effect of sediment input from all sources in the watershed. Meadow streams with silt or clay beds were avoided due to inapplicability of the sediment parameters in those streams. The minimum length of response reaches was set at 500 meters with a channel gradient less than 6 percent. The resulting pool of sample sites contains 84 watersheds that drain 80% of total area on the Forest. The remaining 20% of the Forest cannot be monitored with stream surveys because it drains to intermittent channels, private land, or areas that do not have surface streams.

Stratification by Geology

Each watershed on the Forest is stratified by the ability of the dominant parent material to produce sandy sediment. Chief determining criteria is the relative abundance of silica (SiO_2) in the rock (Table 2). Silica-rich rocks typically erode to produce sand-sized particles, while silica-poor rocks generate silt and clay-sized sediments. Watersheds are stratified by the percentage of their drainage area underlain by sand-producing parent material (silicic bedrock map units plus geomorphic landforms). This stratification is based on guidelines from Hilton and Lisle (1993) who predicted that watershed geology would result in two distinct populations of V* data, one for sandy watersheds (with higher V* values) and another for non-sandy watersheds (with lower V* values).

Table 2. Bedrock units used to stratify watersheds into sandy and non-sandy geologies.

Bedrock units producing abundant SAND	Bedrock units producing modest or little SAND
Granitic rocks, quartz-bearing schistose rocks, shale, siltstone, sandstone (greywacke), conglomerate, chert, quartzite, diorite, unconsolidated materials (e.g., glacial deposits, stream terraces, outwash deposits), tuff, pyroclastic rocks, cinders, rhyolite, rhyodacite, pumice	Slate, gabbro, undifferentiated metamorphic, undifferentiated metasediments, mudstone, ultramafic rocks, limestone, mélange units, undifferentiated volcanic rocks (including basalt, andesite, dacite), undifferentiated metavolcanic rocks

Stratification by Managed and Reference Watersheds

Each watershed on the Forest is designated as either a managed or a reference watershed. Managed watersheds are categorized by the monitoring requirements in the Waiver and MOUs (NCRWQCB 2010, 2004, 2009a, b):

- Category B: Watersheds with projects needing coverage under category B of the 2010 waiver, or with past projects covered under the 2004 waiver.
- Grazed: Required by the MOUs.
- Sediment Control: Streams in this group have had sediment control projects completed in a significant portion of their watershed.
- General: This group contains all managed watersheds not included in the other groups. None of these watersheds have specific monitoring requirements and are sampled at the discretion of the Forest Service.
- Reference: Reference streams are located in watersheds with the least amount of human influence and represent the natural range of conditions resulting from environmental variation. Reference watersheds are used to define desired conditions and serve as benchmarks to measure effects in managed watersheds.

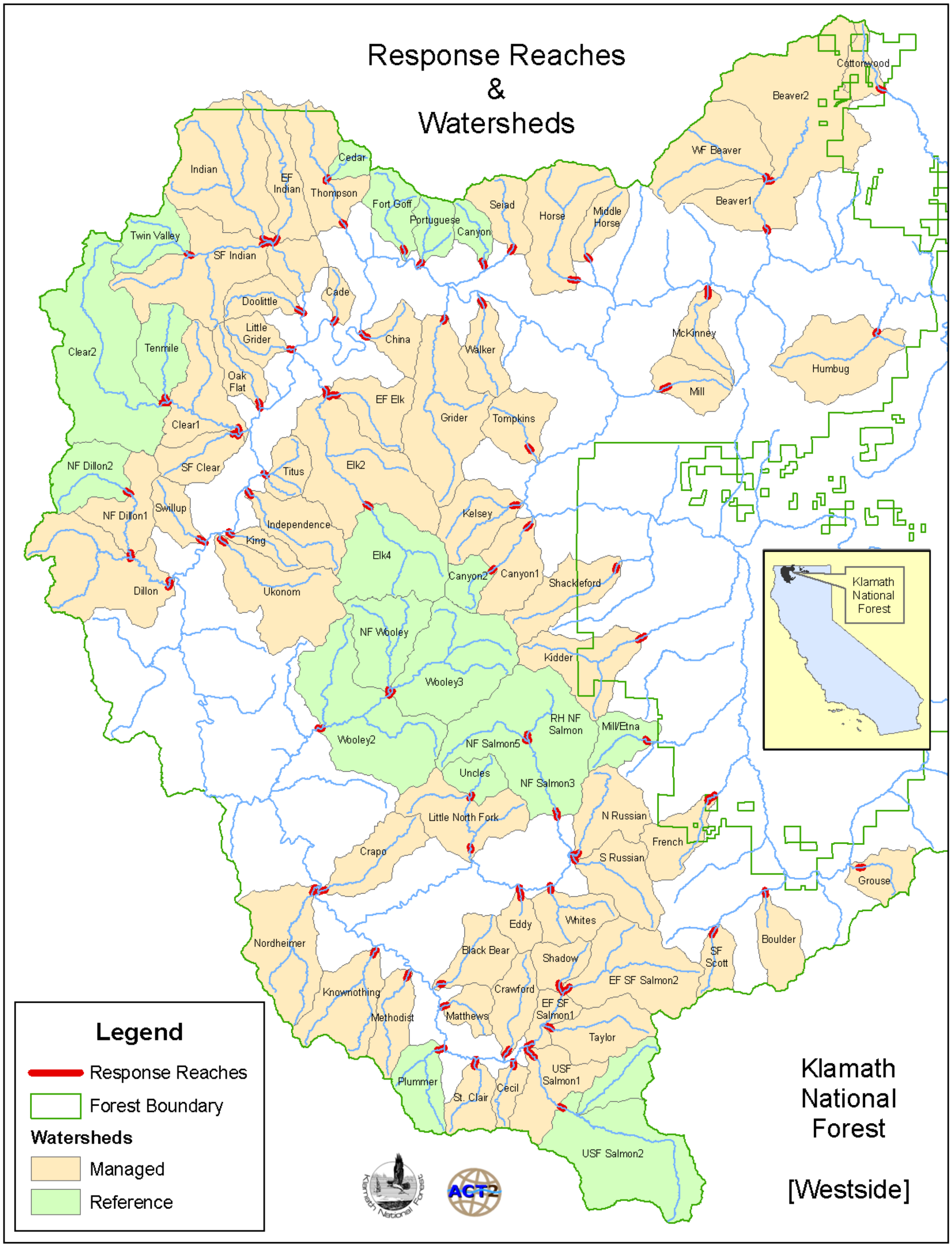

Figure 1a. Monitoring watersheds and response reaches for sediment, Westside.

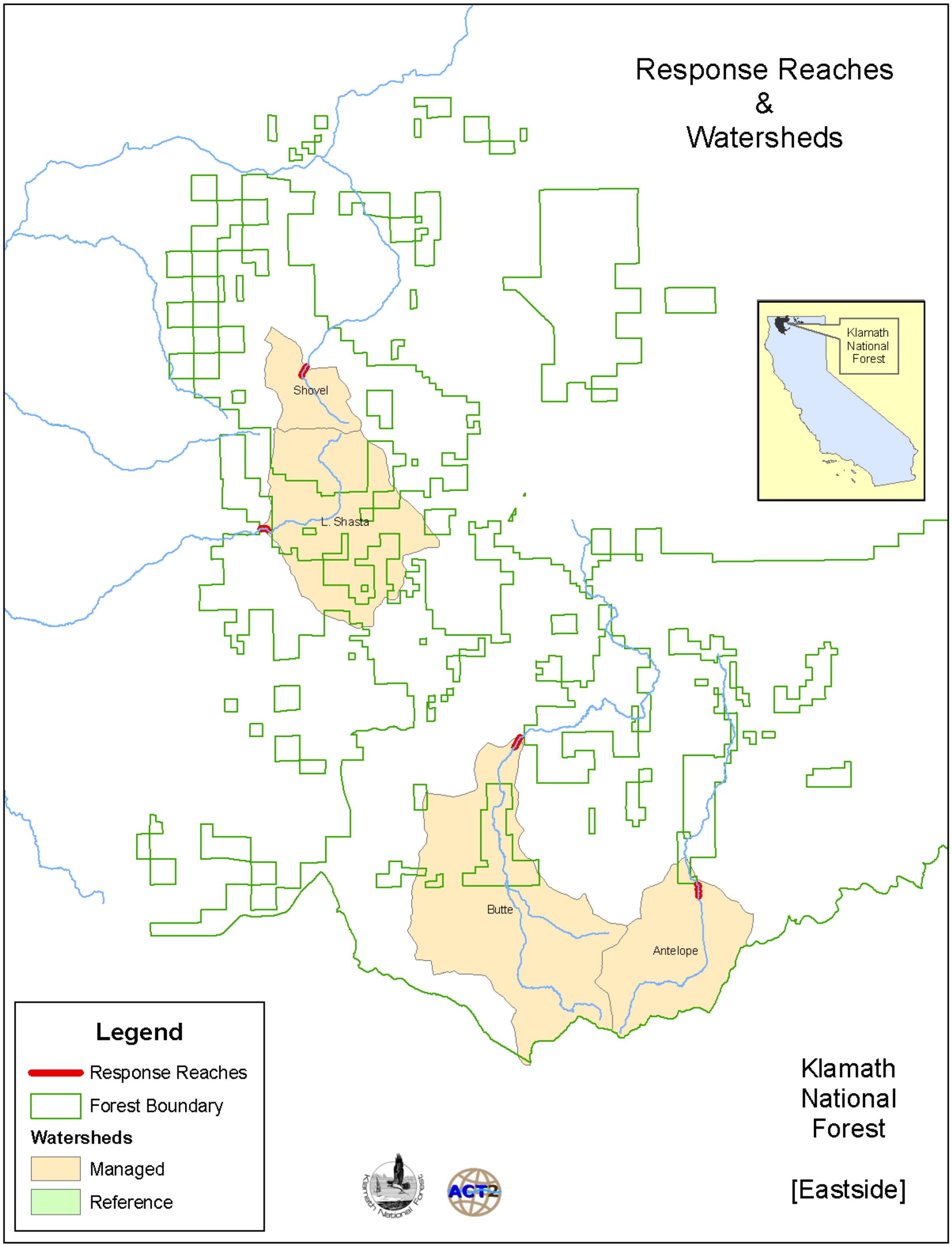

Figure 1b. Monitoring watersheds and response reaches for sediment, Eastside.

Criteria for Selecting Reference Watersheds

The criteria used to select references watersheds followed the SWAMP guidance for establishing and managing reference streams (Ode 2009). Watersheds are considered a candidate reference if they meet the criteria in Table 3. Candidate reference streams that meet these criteria were validated by local Biologists and Geologists using field observations and best professional judgment. A total of 20 reference streams were identified. Of these, 11 are considered near-pristine because they have no roads and most are located in wilderness areas. The other 9 reference watersheds are considered minimally disturbed with road densities less than 0.19 km/km^2 (Table 5). Several reference watersheds have a small portion of their area in grazing allotments, but have no substantial grazing-related sediment sources. Most of the reference watersheds have a history of disturbance by wildfire and floods and are included in the reference pool as of component of natural variability. Reference streams are well distributed across the forest except for the east side (Goosenest) where no streams met the minimum criteria. The characteristics of the reference watersheds have a similar range as managed streams, and are representative of the background condition of the managed watersheds (Table 4).

Sediment Supply and Cumulative Effects Models

Management-related disturbance in each watershed was modeled using three Forest Service cumulative watershed effects (CWE) models. The models are commonly used to predict the effects of proposed management activities under the National Environmental Policy Act (NEPA). The GEO model estimates the volume of sediment delivered to the stream channel network by mass wasting from a 10 year storm event (de la Fuente and Haessig 1994). The USLE model estimates chronic sediment delivery from surface erosion from a 2-year 6-hour storm using the universal soil loss equation calibrated with data from local erosion plots (Laurent 2001). Both GEO and USLE predict changes in sediment supply due to natural disturbance such as fire, and from forest management activities such as roads and timber harvest. As described by Cover (2008), the sediment volume estimated by the models is scaled to a stream power index (SPI) to control for differences in transport capacity between streams. The stream power index is defined as the product of channel slope and the peak stream flow having a 2-year recurrence interval (Waananen 1977). This is a modification of the index used by Cover (2009) who used drainage area as a surrogate for stream flow.

The third model used to assess watershed disturbance is the U.S. Forest Service Equivalent Roaded Area (ERA) model. The ERA model is designed to predict the cumulative effect of forest management on the hydrologic function of watersheds (USFS 1988). The model uses coefficients to weight different management activities relative to the effects of a road in terms of altering runoff per unit area of disturbance. The model output is expressed as equivalent roaded acres as a percent of drainage area.

The USLE, GEO, and ERA models all identify a “threshold of concern”, or inference point where the risk of adverse impacts to in-stream beneficial uses becomes a cause for concern. The current model thresholds are based on professional judgment and have not been linked with desired conditions for steam sediment or compliance with state water quality regulations.

Table 3. Reference watershed criteria

Disturbance	Criteria
Road density	Less than 0.19 km/km^2 (0.30 mi/mi^2) with no significant road failures.
Grazing	Less than 10% of the drainage area grazed, and no BMP violations. Most have no grazing.
Mining	No significant sediment input or point sources (metals or pH). Most have only prospects.
Timber harvest	A road density of less than 0.19 km/km^2 is used as surrogate for past harvest intensity.
Wildfire and other natural disturbance	Natural disturbance must be included in the reference pool as of component of natural variability. .

Table 4. Characteristics of reference and managed watersheds. (Not all of the managed streams have been surveyed yet)

	Reference Streams (n = 20)			Managed Streams (n = 64)		
Watershed Characteristics	Average	Maximum	Minimum	Average	Maximum	Minimum
Drainage Area (km^2)	70	291	13	66	272	12
Mean Elevation (m)	1437	1754	1147	1311	1946	760
Maximum Elevation (m)	2179	2715	1811	2080	2715	1286
Minimum Elevation (m)	711	1286	393	639	1791	231
Precipitation (Mean Annual) (in)	73	100	53	56	87	29
Road Density (km/km^2)	0.03	0.19	0.00	1.62	3.58	0.14
Sandy geology (%of drainage area)	44	95	13	47	100	0
Channel Gradient (%)	3.3	6.5	1.1	3.4	6.6	0.5
Reach Length (m)	790	1811	405	767	1622	457

Table 5. Site characteristics and field data for streams surveyed in 2009 and 2010.

		Site Characteristics				Roads		Modeled Sediment Volume		In-Stream Sediment Indicators			
Stream	Year	Management Pool	Drainage Area (km^2)	Channel Slope	% of Drainage w/Sandy Geology	Road Density (km/km^2)	Equivalent Roaded Area (%)	Sediment Supply USLE (m^3/km^2)	Sediment Supply GEO (m^3/km^2)	V*	Surface Fines <2mm (%)	Subsurface Fines <6.35mm (%)	Subsurface Fines <0.85mm (%)
Canyon/Scott 2	2009	Reference	21	0.041	39	0.13	0.6	6.6	41.3	0.112	3.2	42.8	10.9
Cedar	2009	Reference	13	0.051	23	0.00	0.0	5.7	40.5	0.090	2.4	40.0	15.2
Elk 4	2009	Reference	83	0.024	76	0.00	3.1	15.5	106.9	0.121	4.2	61.6	20.8
Fort Goff 1	2009	Reference	34	0.038	82	0.01	1.6	4.4	74.9	0.094	2.2	51.1	19.6
Mill /Etna	2009	Reference	27	0.054	30	0.06	0.1	6.6	51.0	0.032	2.1	32.8	10.3
Portuguese 1	2009	Reference	23	0.033	88	0.06	1.9	4.9	55.7	0.074	2.5	45.6	12.7
Twin Valley	2009	Reference	36	0.053	22	0.00	0.0	11.8	33.4	0.054	1.2	30.1	7.8
Uncles	2009	Reference	21	0.065	54	0.00	4.7	11.6	114.0	0.111	7.2	47.0	19.9
Upper S.F. Salmon 2	2009	Reference	156	0.011	95	0.19	1.8	11.0	66.4	0.050	5.0	41.6	15.9
Canyon Seiad	2010	Reference	18	0.052	95	0.03	0.0	5.1	64.6	0.092	3.5	38.7	12.1
Clear 2	2010	Reference	160	0.015	19	0.00	0.0	9.5	41.6	0.029	3.3	*	*
N.F. Dillon 2	2010	Reference	44	0.028	26	0.15	0.0	12.7	59.7	0.030	2.0	28.7	6.8
N.F. Salmon 3	2010	Reference	146	0.018	15	0.04	0.0	7.4	32.8	0.044	0.4	32.9	10.1
N.F. Salmon 5	2010	Reference	48	0.020	32	0.00	0.0	8.6	32.6	0.077	12.1	29.4	8.3
N.F. Wooley	2010	Reference	57	0.058	46	0.00	0.0	11.4	58.8	0.069	7.5	29.8	8.0
Plummer	2010	Reference	37	0.035	13	0.00	0.0	7.6	41.1	0.035	0.6	29.5	8.6
Right Hand N.F. Salmon	2010	Reference	51	0.030	13	0.00	0.0	7.4	34.1	0.051	1.6	32.9	12.4
Tenmile	2010	Reference	41	0.031	50	0.00	0.0	9.6	95.6	0.026	3.6	38.4	10.3
Wooley 2	2010	Reference	299	0.025	40	0.02	0.0	9.6	56.3	0.030	2.9	34.2	10.8
Wooley 3	2010	Reference	105	0.026	21	0.00	0.0	7.1	42.5	0.127	6.7	33.6	11.5
Cade	2009	Cat B Projects	12	0.034	72	2.78	9.4	11.0	145.3	0.190	8.0	52.0	22.5
Clear 1	2009	Cat B Projects	256	0.005	26	0.14	0.5	9.2	59.9	0.013	1.5	28.5	9.0
Dillon 1	2009	General	190	0.013	30	0.47	4.3	16.5	93.0	0.065	0.3	28.0	7.5
Grider 1	2009	Sed. Control	102	0.027	31	0.88	0.8	9.4	69.2	0.054	3.7	47.0	15.8
Haypress	2009	Grazing	17	0.053	100	0.75	1.4	13.6	97.40	0.054	8.6	53.6	18.0
Little Grider	2009	Cat B Projects	21	0.030	1	1.71	2.4	22.6	79.1	0.139	5.0	46.0	16.1
Little N.F. Salmon 1	2009	Sed. Control	80	0.027	57	0.38	4.5	11.4	111.6	0.099	3.7	43.4	13.9
Middle Horse	2009	Cat B Projects	24	0.032	100	3.58	7.9	35.6	99.5	0.246	7.9	52.2	24.5
Shackleford	2009	Grazing	48	0.038	37	1.13	3.3	8.7	41.7	0.037	2.0	47.6	17.1
Steinacher	2009	Sed. Control	37	0.044	56	0.25	2.8	7.6	77.0	0.181	8.1	41.9	13.6
Thompson 2	2009	Sed. Control	71	0.029	31	0.56	0.6	6.2	50.2	0.031	1.9	42.0	12.6
W.F. Beaver 1	2009	Cat B Projects	81	0.021	77	3.42	7.7	22.8	69.8	0.143	3.1	45.6	16.9
Beaver 1	2010	Cat B Projects	272	0.019	66	3.18	0.1	15.4	59.4	0.053	3.0	44.2	18.2
Beaver 2	2010	Cat B Projects	152	0.038	65	3.20	0.1	13.3	61.4	0.076	3.6	44.0	16.0
Canyon Scott 1	2010	Grazing	64	0.055	32	0.66	0.0	7.2	55.7	0.053	1.8	28.6	9.5
Horse 1	2010	Cat B Projects	74	0.028	96	2.82	0.0	21.5	73.5	0.237	4.3	46.6	20.0
Humbug 1	2010	Cat B Projects	74	0.023	31	1.63	0.0	6.6	39.0	0.136	6.8	44.0	16.0
McKinney	2010	General	29	0.031	35	2.66	0.1	11.2	72.2	0.239	13.1	45.5	21.8
Swillup	2010	Cat B Projects	23	0.045	29	1.09	0.0	12.5	103.8	0.120	7.5	39.7	12.3

*/ No samples obtained – potential gravel patches were too shallow and/or substrate material was too large

RESULTS

Between 2009 and 2010 we sampled 39 streams, or 46% of all the watersheds in Figure 1. The sites included 20 reference streams and 19 managed streams (Table 5). Most of the data were collected by the Northern California Resource Center, a non-profit organization that is independent from the Forest Service. The quality of the data is considered good with very few problems encountered during field sampling.

Survey Error and Natural Variability

We estimated precision of each sediment indicator using 9 repeat surveys. Repeat surveys included 3 pairs of successive measurements by the same crews in the same reaches, and 6 pairs between different crews. Variation between successive surveys is greatest for surface sediment and least for V* (Table 7). The standard deviation of the differences for all pairs is used to the represent the total variability in the dataset (the survey error).

Reference Conditions

The "reference condition" was calculated for each watershed using the 75th percentile of reference values plus the standard deviation of the differences between repeat surveys (Table 8). The reference condition is a good indicator of management effects because it discriminates well between reference and managed streams (Figures 3 and 4). The reference condition includes the bulk of the reference values while excluding high values in burned watersheds such as in Elk Creek (Figure 2c).

The state's desired condition values do not discriminate between managed and reference conditions. Compared to reference streams, the state's desired condition overestimates V* and underestimates subsurface fines (Figure 4). Most of the reference streams cannot attain the state values for subsurface fines <6.35mm.

The Forest Service standard for surface sediment appears to be too high. The Forest Plan standard of 15% is higher than the maximum value in both reference and managed streams (Figure 4).

The percent of the watershed with sandy geology is significantly correlated with subsurface sediment (<6.35mm: $r^2 = 0.45$, and <0.85mm: $r^2 = 0.32$), but not with pool and surface sediment (Figure 2). The strength of the relation with percent sandy geology is affected by three high values in sandy watersheds that experienced recent wildfires (Uncles, Elk, and Ft. Goff). However, other watersheds such as Dillon Creek and the Upper South Fork Salmon also experienced wildfires but have low sediment.

Management Effects on In-stream Sediment

The effect of management on stream sediment is evaluated using a weight-of-evidence approach based on the number of indicators exceeding the reference condition, and the relative sediment supply from human-caused sources (Table 9). Of the nineteen managed streams we surveyed, nine have sediment values less than the reference condition for all four indicators (Table 10). There is no evidence that sediment has been altered in these streams. Another ten streams have sediment values greater than the reference condition for at least one indicator (Table 10, Fig. 3). To determine if human-related sediment sources could have caused the high values, the dominant sediment source in each watershed is estimated using the Forest Service GEO and USLE models. The models show that roads supply >50% of the total sediment in seven of the ten managed watersheds (Table 11). The other three watersheds, Haypress, Steinacher, and Swillup Creeks, have a very high sediment supply from natural sources (background + wildfire). However, the Steinacher Creek watershed has a road decommissioning project located directly above the monitoring reach that failed an on-site BMP evaluation. In addition, five reference streams exceed the reference condition for at least one indicator (Figure 2). Nearly all of the sediment supply in the reference watersheds is from natural sources (Table 11).

The effect of management on in-stream sediment is also assessed by comparing the entire distribution of sediment values in reference and managed streams. An increase in sediment supply appears to have skewed the overall distribution of fine sediment in the managed streams (Figure 5). Compared to reference streams, the median V* value increased by about 0.02, surface sediment by 0.5%, subsurface <6.5mm by 7%, and subsurface <0.85mm by 5%.

Thresholds for Cumulative Watershed Effects Models

A regression analysis similar to the one by Cover (2008) was developed using modeled sediment supply and equivalent roaded area as predictor variables, and V*, surface sediment, and sub-surface sediment as response variables. The sediment volumes predicted by the USLE and GEO models were divided by a stream power index (SPI) and then log-transformed to meet the assumptions for linear regression. The results show that subsurface sediment is significantly correlated with USLE and GEO sediment supply, equivalent roaded area, and the percent of the watershed with sandy geology (Tables 12, 13 and 14). The portion of pools filled with sediment (V*) and percent surface sediment are significantly correlated with USLE, GEO, and ERA but not with the percent of the watershed in sandy geology. Although significant, the correlations are very weak ($r^2 = 0.12$ to 0.53) and have wide confidence limits.

New thresholds for the CWE models can be identified where the regressions predict attainment of the reference condition for in-stream sediment. However, in most cases the lower 95th confidence limit does not intercept the reference condition (Figures 6a,b and 7a,b).

SUMMARY AND CONCLUSIONS

Reference conditions derived from minimally disturbed watersheds can be used as benchmarks to measure sediment impacts in managed streams. The 75th percentile of the reference values plus the measurement variability is a good indicator of management effects because it discriminates between reference and managed streams. The current Forest Service standard for surface sediment and the desired conditions used by the Regional Water Board are poor indicators of management effects because they do not discriminate between managed and reference streams.

In nine of the nineteen managed watersheds in our survey, in-stream sediment is less than the reference condition for all four indicators. Although some of these watersheds have been heavily managed there is no evidence that in-sediment has been altered or that beneficial uses have been impaired. We conclude that the Aquatic Conservation Strategy objective for maintaining the natural sediment regime is fully attained in these streams.

Of the nineteen managed streams, ten have sediment values greater than the reference condition for at least one indicator (Table 9). We conclude that seven of these streams have adverse impacts due to human-caused sediment sources, and are not attaining the Aquatic Conservation Strategy objective for maintenance of the natural sediment regime.

Our data verifies that the Forest Service CWE models are meaningful indicators of the effects of management on beneficial uses. We found significant but weak correlations between instream sediment and the sediment supply predicted by the GEO and USLE models. In-stream sediment is also correlated with percent equivalent roaded area. Our correlations are much weaker than those of Cover (2008), probably because our data includes watersheds with non-granitic parent material. Subsurface sediment is significantly correlated with the percent of the watershed with sandy geology, but V* and surface sediment are not. The regression models are adequate to predict the relative cumulative effects of different management activities assessed for the National Environmental Policy Act. However, the regressions are not adequate to predict model thresholds for attainment of reference conditions because the lower confidence limit does not intercept the reference condition. Additional data may be required before a stronger relationship can be established.

Table 7. Variability of sediment indicators for pairs of repeat surveys at the same site (survey error). Pairs are either within the same crew or between different crews. The "survey error" is the standard deviation of the differences.

			V* (%)			Surface Fines (%)			SubSurface Fines <6.35 mm (%)			SubSurface Fines <.85 mm (%)		
Stream Name	Year Surveyed	Pair	Crew 1	Crew 2	Difference	Crew 1	Crew 2	Difference	Crew 1	Crew 2	Difference	Crew 1	Crew 2	Difference
Plummer	2010	within	0.032	0.037	-0.005	0.4	0.7	-0.30	26.3	32.6	-6.30	6.9	10.2	-3.30
Tenmile	2010	within	0.027	0.025	0.002	4.0	3.1	0.90	42.2	34.6	7.60	12.1	8.4	3.70
Swillup	2010	within	0.129	0.111	0.018	10.5	4.5	6.00	35.9	43.5	-7.60	10.2	14.3	-4.10
Beaver 2	2010	between	0.073	0.079	-0.006	2.6	4.5	-1.90	43.1	44.9	-1.80	14.0	17.9	-3.90
Canyon Scott 1	2010	between	0.056	0.049	0.007	0.5	3.1	-2.60	27.9	29.2	-1.30	10.6	8.3	2.30
Humbug 1	2010	between	0.165	0.107	0.058	8.5	5.1	3.40	41.0	47.0	-6.00	14.3	17.6	-3.30
Grider (Crews A – B)	2009	between	0.046	0.056	-0.010	4.8	2.7	2.10	42.4	45.6	-3.20	14.7	15.3	-0.60
Grider (Crews B – C)	2009	between	0.056	0.060	-0.004	2.7	3.6	-0.90	45.6	53	-7.40	15.3	17.4	-2.10
Grider (Crews C – A)	2009	between	0.060	0.046	0.014	3.6	4.8	-1.20	53	42.4	10.60	17.4	14.7	2.70
Mean Difference					0.008			0.61			-1.71			-0.96
Coeff. of Variation					2.625			4.57			3.85			3.22
Standard Deviation of Differences					**0.021**			**2.79**			**6.59**			**3.09**

Table 8. Summary statistics for reference streams.

	Pool Sediment (V*)	Surface Sediment <2mm (%)	Sub-Surface Sediment <6.35mm (%)	Sub-Surface Sediment <0.85mm (%)
N	20	20	19	19
Mean	0.067	3.7	37.9	12.2
Maximum	0.127	12.1	61.6	20.8
Minimum	0.026	0.4	28.7	6.8
Standard Deviation	0.034	2.8	8.8	4.2
Coefficient of Variation	0.51	0.76	0.23	0.34
75th Percentile	0.0935	4.8	42.8	15.2
Reference Condition = 75th percentile + Survey Error	**0.115**	**7.6**	**49.4**	**18.3**

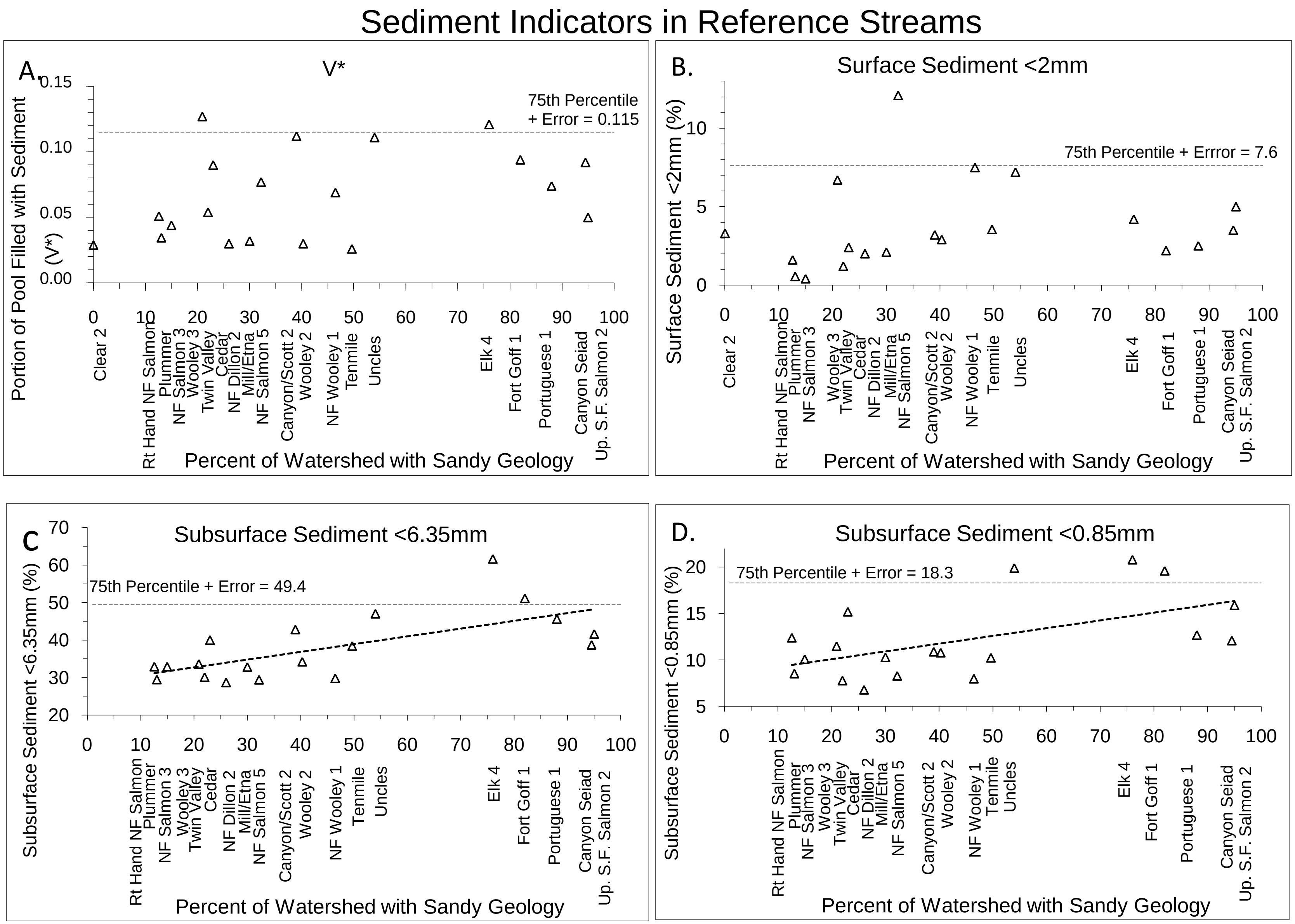

Figure 2. Sediment indicators in reference streams.

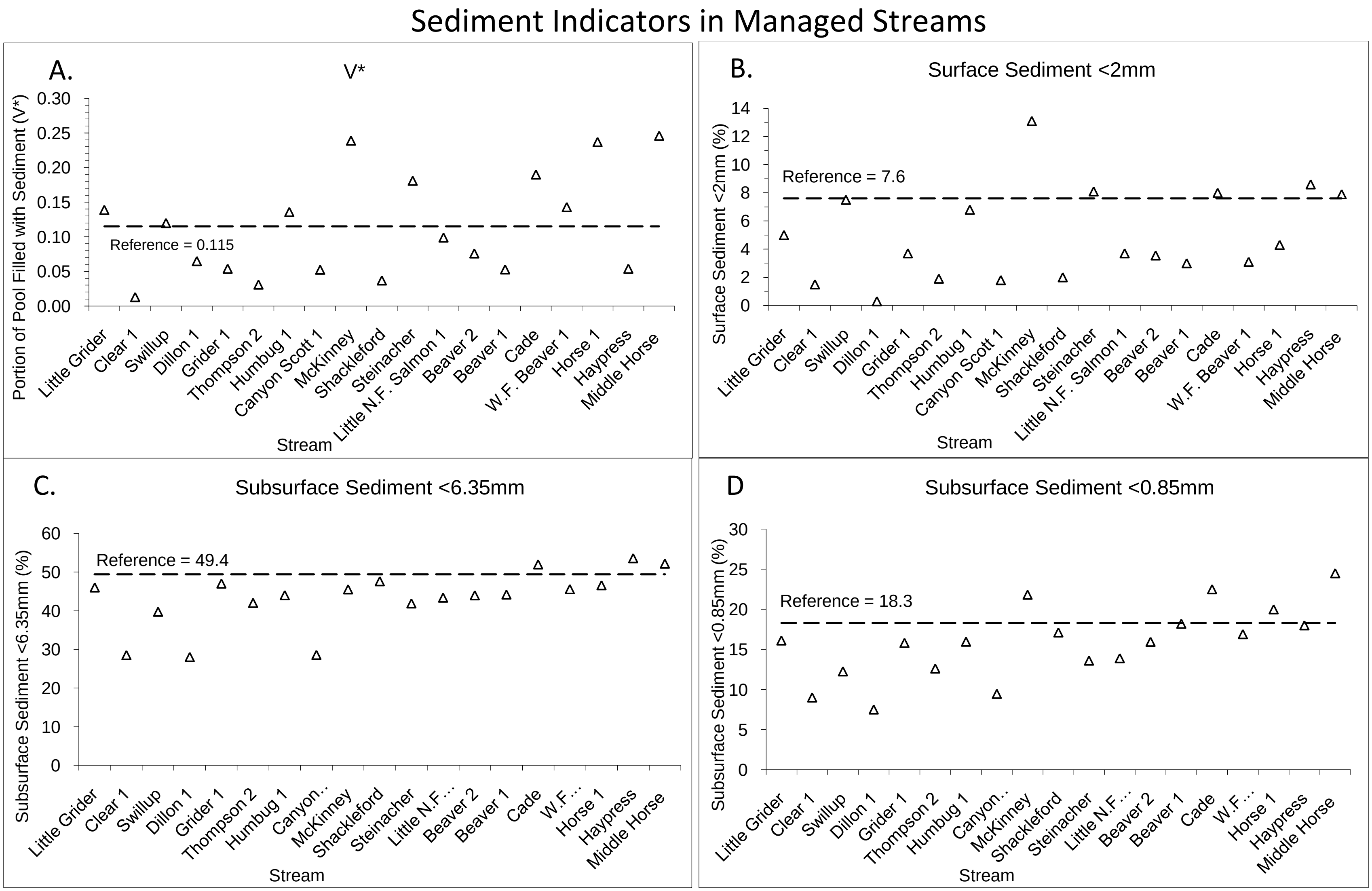

Figure 3. Sediment indicators in managed streams. Streams are sorted by increasing percent of watershed with sandy geology.

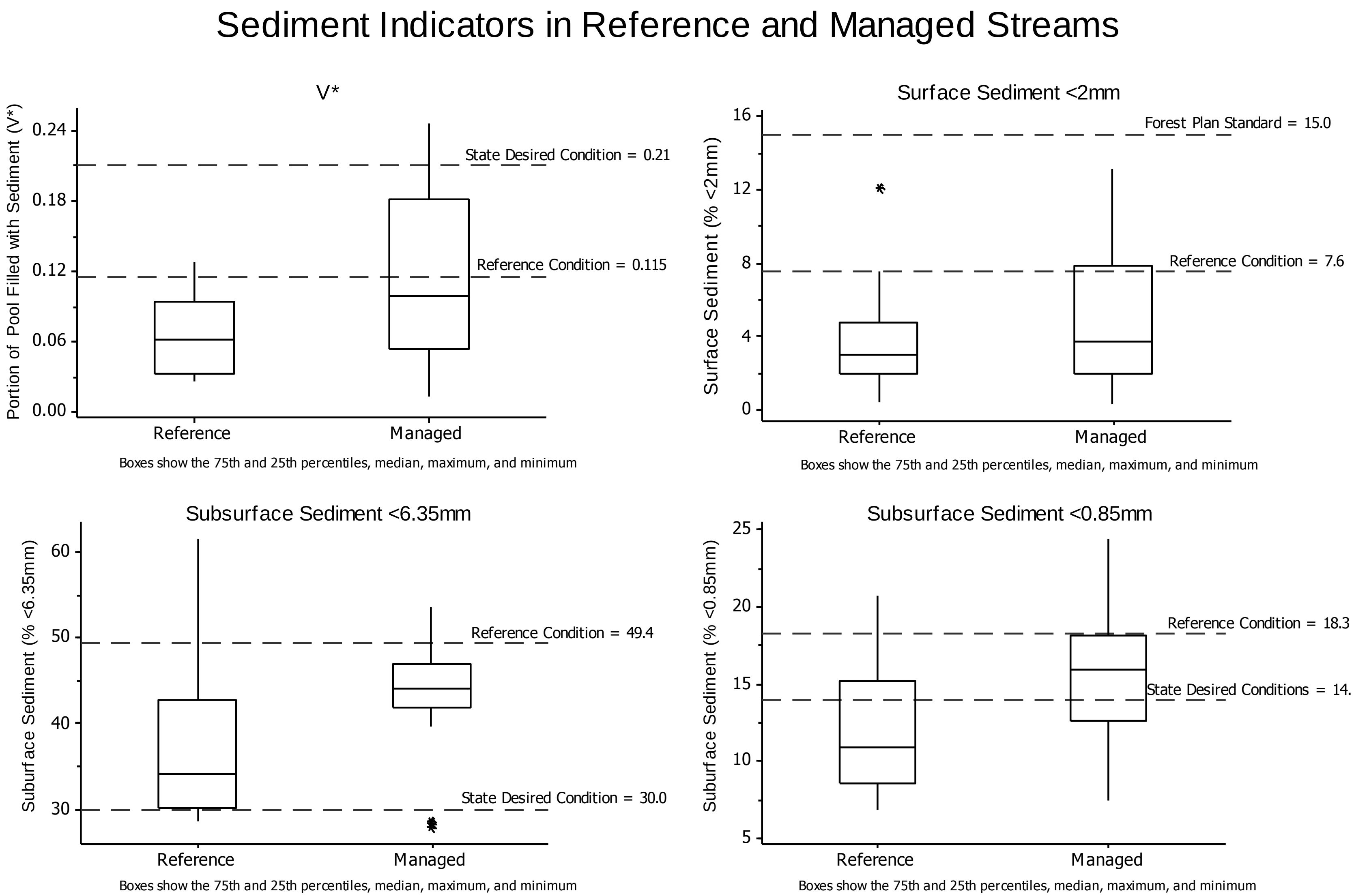

Figure 4. Comparison of desired conditions from the North Coast Regional Water Board with the reference condition calculated from reference streams. The reference condition consistently excludes outliers (*) while including most of the reference values.

Table 9. Interpretation of adverse effects due to human-caused sediment sources.

Effects (Number of Indicators >Reference Condition)	Dominant Sediment Source	Beneficial Use Support	Interpretation
3 to 4	Human-caused sources supply >50% of the total sediment	Not Supporting	Adverse effects. Human-related sediment sources are the likely cause
1 to 2			Possible adverse effects. Human-related sediment sources are the likely cause
1 to 2	Human-caused sources supply <50% of the total sediment	Partially Supporting	Possible adverse effects. Cause could be from either human-related or natural sediment sources
Any	Natural sources supply ≥99% of total sediment	Supporting	No substantial human-related sediment sources.
0	Any		No adverse effects

Table 10. Managed streams attaining and not attaining reference conditions. The >50% of the sediment supply in watersheds with an * is from background and wildfire sources (Table 11).

Managed Watersheds	V*		% Surface <2mm		% Sub-Surface <6.35mm		% Sub-Surface <0.85mm		Total # of Indicators >Reference
	> Reference	< Reference	> Reference	< Reference	> Reference	< Reference	> Reference	< Reference	
Cade	X		X		X		X		4
Middle Horse	X		X		X		X		4
McKinney	X		X			X	X		3
Horse 1	X			X		X	X		2
Little Grider	X			X		X		X	1
W.F. Beaver 1	X			X		X		X	1
Humbug 1	X			X		X		X	1
Steinacher *	X		X			X		X	2
Haypress *		X	X		X			X	2
Swillup*	X			X		X		X	1
Clear 1		X		X		X		X	0
Dillon 1		X		X		X		X	0
Grider 1		X		X		X		X	0
Little N.F. Salmon1		X		X		X		X	0
Shackleford		X		X		X		X	0
Thompson 2		X		X		X		X	0
Beaver 1		X		X		X		X	0
Beaver 2		X		X		X		X	0
Canyon Scott 1		X		X		X		X	0
Total Managed	9	10	5	14	3	16	4	15	21

Table 11. Sediment sources in watersheds exceeding the reference condition for in-stream sediment. Sediment sources are estimated from the Forest Service GEO, USLE, and ERA models. Note that five reference streams have values greater than the reference condition due to high background sediment and natural disturbances.

Watershed	Background (% of total)			Fire (% of total)			Harvest (% of total)			Roads (% of total)		
	USLE	GEO	ERA	USLE	GEO	ERA	USLE	GEO	ERA	USLE	GEO	ERA
Cade	37	34	na	0	28	43	3	2	27	60	36	31
Middle Horse	16	46	na	0	0	0	0	7	59	84	47	41
McKinney	21	42	na	0	0	0	0	18	59	79	40	41
Horse 1	30	62	na	0	2	4	0	7	29	70	29	67
Steinacher	76	48	na	21	44	93	0	0	0	3	8	7
Haypress	54	63	na	11	7	51	0	6	1	36	25	48
Little Grider	18	58	na	1	1	7	1	3	20	80	39	73
W.F. Beaver 1	14	76	na	0	0	0	1	5	59	85	19	41
Humbug	38	57	na	0	0	0	2	0	8	61	43	92
Swillup	58	58	na	0	24	46	0	0	30	42	17	25
Reference Streams												
Elk 4	64	34	na	37	66	100	0	0	0	0	0	0
Ft. Goff 1	100	60	na	0	40	99	0	0	1	0	0	0
Uncles	75	31	na	25	69	100	0	0	0	0	0	0
N.F. Salmon 5	99	98	na	1	2	100	0	0	0	0	0	0
Wooley 3	99	95	na	1	5	100	0	0	0	0	0	0

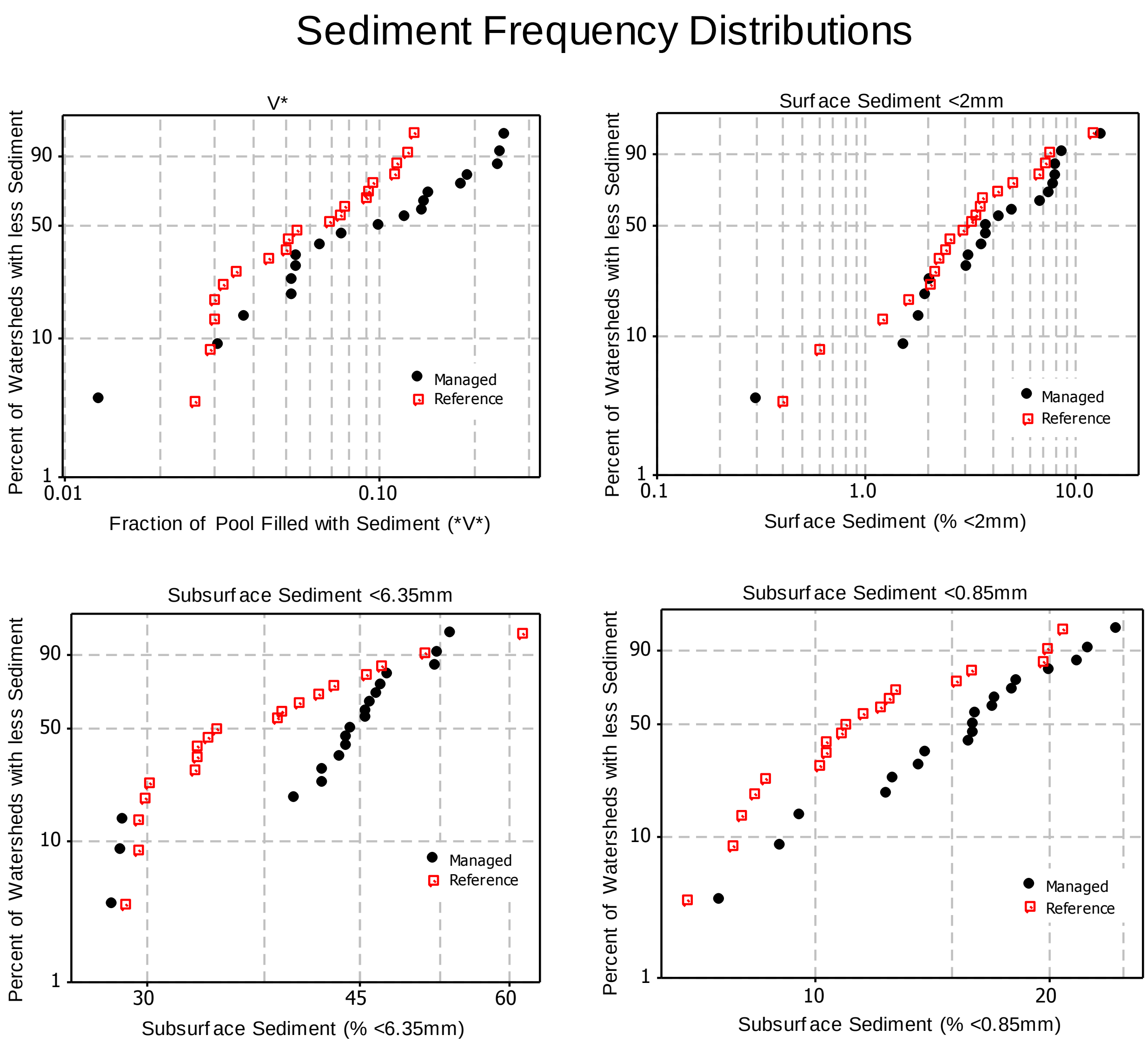

Figure 5. Distribution of sediment indicators in managed and reference streams (Weibull distribution). The distribution in managed streams is shifted to the right indicating a greater percentage of streams with high sediment values.

Table 12. Regression models for stream response to USLE and GEO modeled sediment supply, and equivalent roaded area. All models are significant at $\alpha = 0.05$.

CWE Model	Equation $Y = a + b(X_1) + c(X_2)$	R^2 (%)	p-value
USLE	V* = -0.0545 + 0.0546 ln(USLE/SPI)	38.1	<0.001
	Surface Sediment = -1.74 + 2.28 ln(USLE/SPI)	27.0	0.001
	Subsurface <6.35 = 22.6 + 3.90 ln(USLE/SPI) + 0.157 (% Sandy)	47.0	USLE/SPI: 0.017 % Sandy: <0.001
	Subsurface <0.85 = 2.05 + 3.17 ln(USLE/SPI) + 0.0730 (% Sandy)	52.7	USLE/SPI: <0.001 % Sandy: 0.001
GEO	V* = - 0.114 + 0.0457 ln(GEO/SPI)	29.9	<0.001
	Surface Sediment = - 5.25 + 2.14 ln(GEO/SPI)	26.6	0.001
	Subsurface <6.35 = 13.4 + 4.55 ln(GEO/SPI) + 0.138 (% Sandy)	50.4	GEO/SPI: 0.005 % Sandy: 0.001
	Subsurface <0.8 = - 2.33 + 2.94 ln(GEO/SPI) + 0.0650 (% Sandy)	49.8	GEO/SPI: 0.001 % Sandy: 0.005
ERA	V* = 0.0523 + 0.0152 (ERA)	38.7	<0.001
	Surface Sediment = 3.25 + 0.424 (ERA)	12.3	0.029
	Subsurface <6.35 = 31.2 + 0.988 (ERA) + 0.142 (% Sandy)	44.3	ERA: 0.046 % Sandy: 0.002
	Subsurface <0.8 = 8.96 + 0.968 (ERA) + 0.0539 (% Sandy)	53.4	ERA: <0.001 % Sandy: 0.019

Where:
USLE = Sediment supply ($m^3/km^2/yr$) predicted by the USLE model
GEO = Sediment supply ($m^3/km^2/yr$) predicted by the GEO model
ERA = Equivalent roaded area (5 of watershed area)
SPI = Stream power index (Q_2/slope) of response reach
% Sandy = Percent of watershed with sandy geology

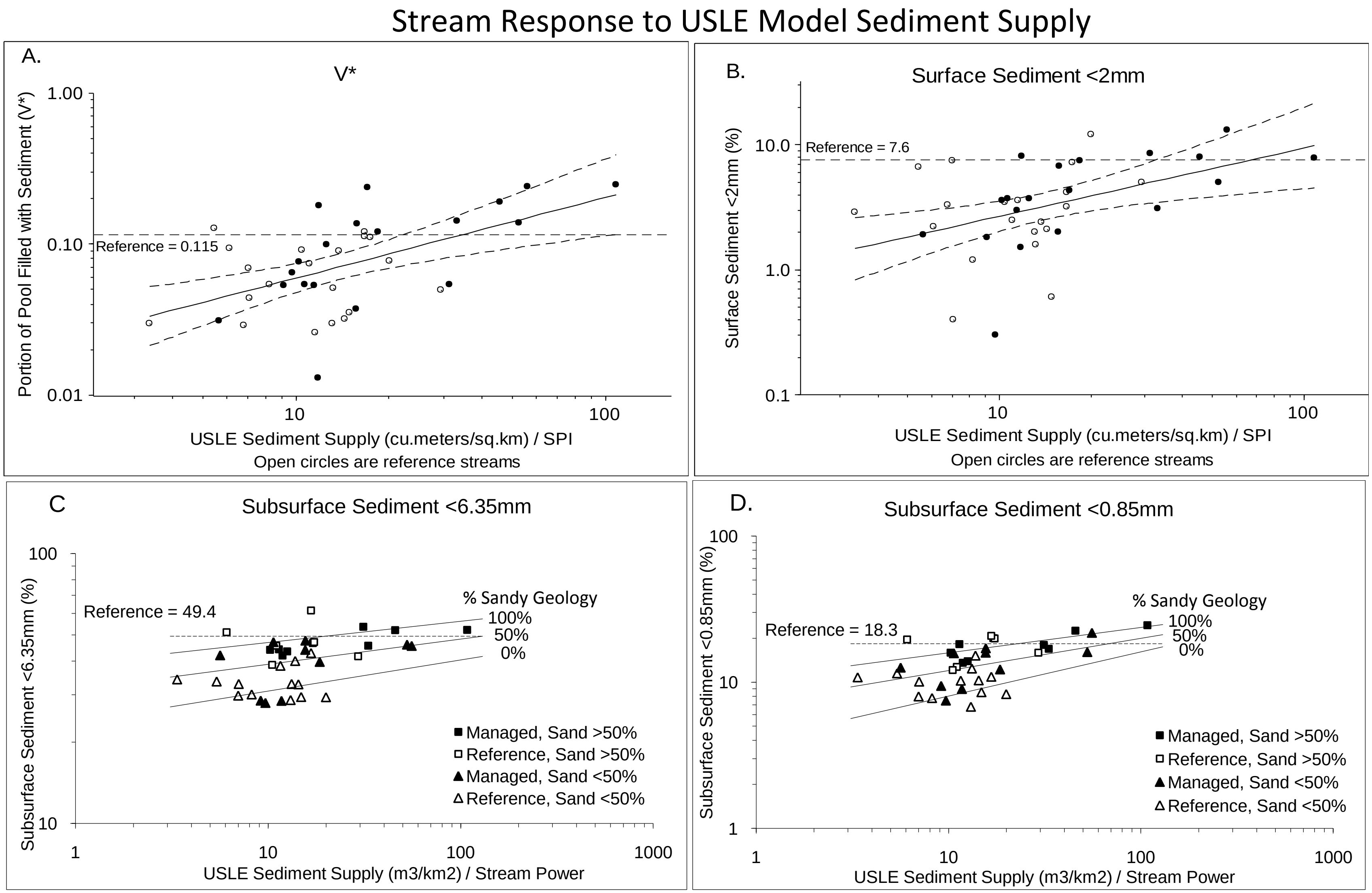

Figure 6. Stream response to USLE sediment supply. Figures C and D are multiple regressions of subsurface sediment with USLE sediment supply and percent of the watershed with sandy geology as predictors. V* and surface sediment are correlated only with USLE (Fig. A and B).

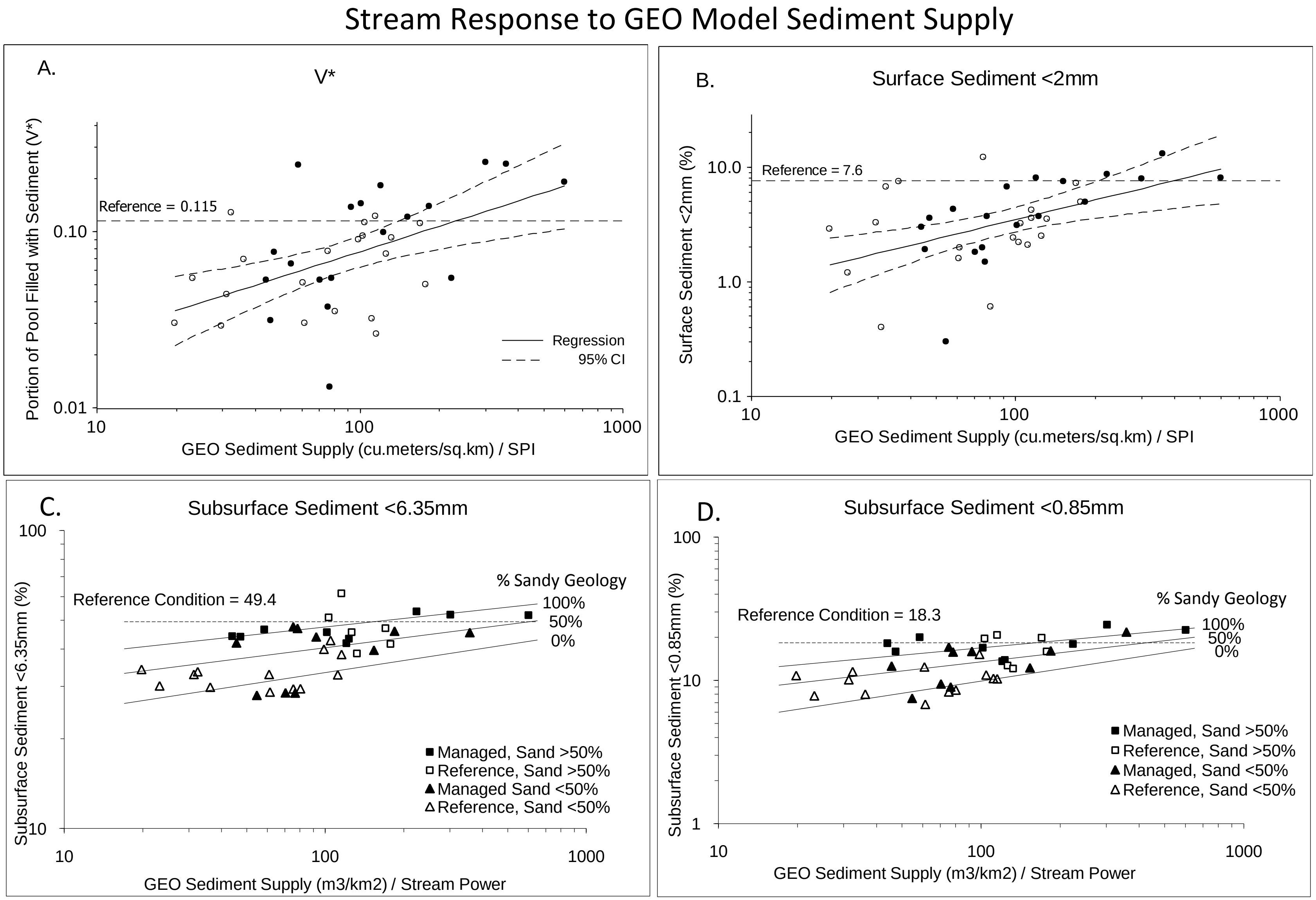

Figure 7. Stream response to GEO sediment supply. Figures C and D are multiple regressions of subsurface sediment with GEO sediment supply and percent of the watershed with sandy geology as predictors. V* and surface sediment are correlated only with GEO (Fig. A and B).

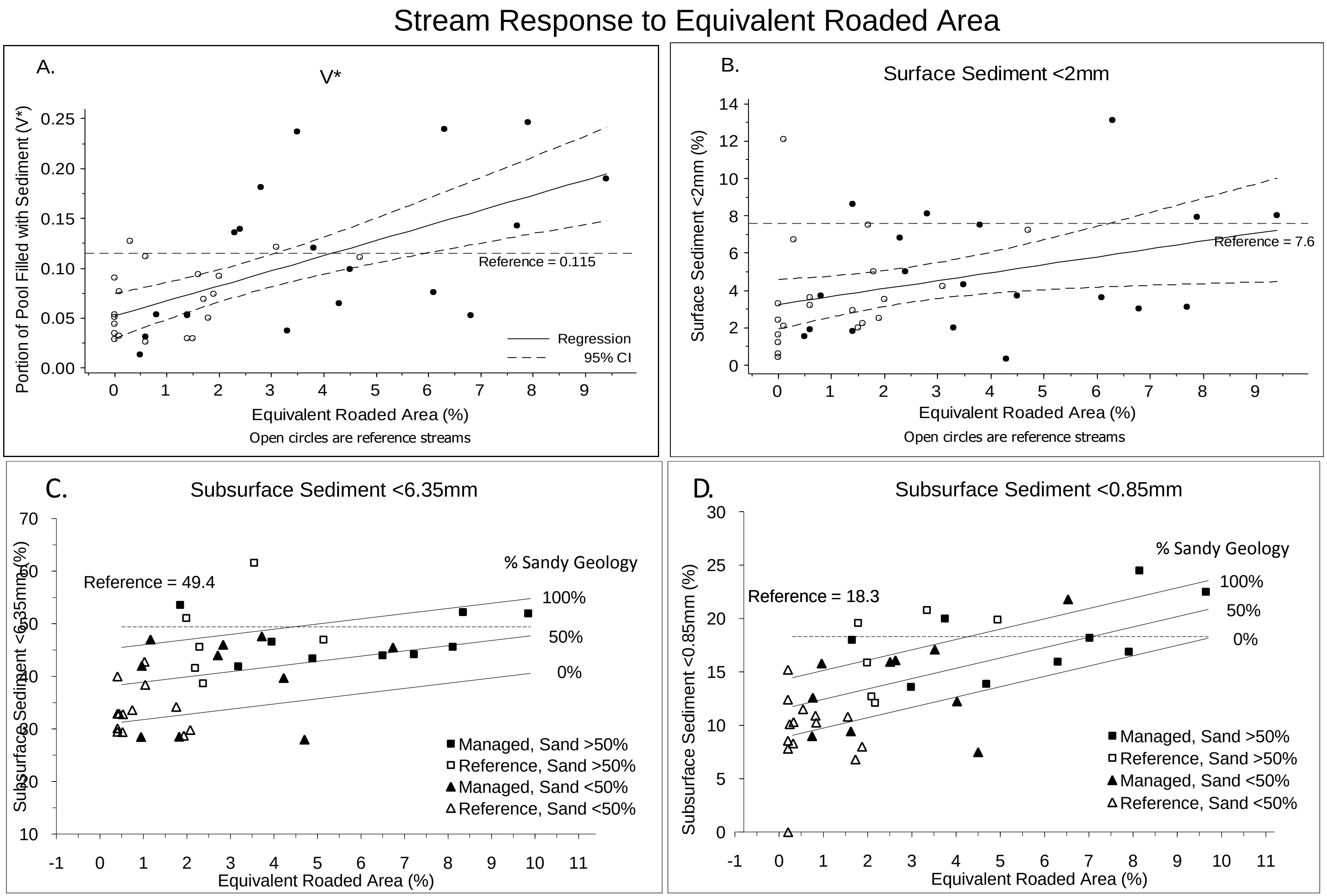

Figure 8. Stream response to equivalent roaded area (%). Figures C and D are multiple regressions of subsurface sediment with ERA and percent of the watershed with sandy geology as predictors. V* and surface sediment are correlated only with ERA (Fig. A and B).

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